The following Papers were read :—

I. "On determining the Depth of the Sea without the use of the Sounding-line, and on an Attraction-meter." By C. WILLIAM SIEMENS, D.C.L., F.R.S., M.I.C.E. Received January 20, 1876.

(Abstract.)

The author starts with the proposition that the total gravitation of the earth, as measured on its normal surface, is composed of the separate attractions of all its parts, and that the attractive influence of each equal volume varies directly as its density and inversely as the square of its distance from the point of measurement.

The density of sea-water being about 1·026, and that of the solid constituents composing the crust of the earth about 2·763 (this being the mean density of mountain-limestone, granite, basalt, slate, and sandstone), it follows that an intervening depth of sea-water must exercise a sensible influence upon total gravitation if measured on the surface of the sea.

The amount of this influence is proved mathematically in considering, in the first place, the attractive value of any thin slice of substance in a plane perpendicular to the earth's radius, supposing the earth to be a perfect sphere, unaffected by centrifugal force, and of uniform density.

The attraction of each such slice is shown to be represented by the expression

$$ddA_1 = 2\pi dh \sin \alpha d\alpha,$$

in which h represents the vertical distance to the slice from the point of attraction, and A_1 the total attraction of the slice.

In integrating this expression between the limits h and 0 and α and 0, this gives

$$A_1 = 2\pi h\left(1 - \tfrac{2}{3}\sqrt{\frac{h}{2R}}\right),$$

in which, for small values of h, the factor $\sqrt{\frac{h}{2R}}$ may be neglected, when the formula assumes the form

$$A_1 = 2\pi h,$$

in which A_1 represents the total attraction down to the depth h.

If A represents the total attraction of the earth, the following proportion obtains,

$$\frac{A_1}{A} = \frac{2\pi h}{\frac{4}{3}R\pi},$$

or

$$h = \tfrac{2}{3}R.$$

It follows that if sea-water was without weight, the total attraction of the earth, as measured upon the sea-surface, would diminish in the proportion of the depth to $\frac{2}{3}R$; but taking the weight of sea-water into

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account, gravity would be found to diminish upon the sea-level in the proportion of the depth to $\frac{614}{579}$R, or as R nearly.

The proportion would be strictly correct if the interior of the earth was of the same density as surface-rock; but the coefficient here arrived at has to be diminished in the proportion of the density of surface-rock to the mean density of the earth, or in the proportion of about $\frac{2 \cdot 75}{5 \cdot 4}$; the author considers it safer, however, not to rely entirely upon these mathematical deductions in constructing his working scale, which he prefers to base upon comparison with the sounding-line.

The author next describes a first attempt made by himself in 1859 to construct an instrument to indicate upon a scale such slight variations in total gravitation as would result from the ordinary variations of depth below a vessel, and the difficulties he then encountered. These difficulties he has since succeeded in overcoming in adopting an instrument of another construction, which he proceeds to describe in detail, reference being had to the accompanying drawings.

This instrument, which he proposes to call a *Bathometer*, consists essentially of a vertical column of mercury contained in a steel tube having cup-like extensions at both extremities, so as to increase the terminal area of the mercury. The lower cup is closed by means of a corrugated diaphragm of thin steel plate, and the weight of the column of mercury is balanced in the centre of the diaphragm by the elastic force derived from two carefully tempered spiral steel springs of the same length as the column of mercury.

One of the peculiarities of this mechanical arrangement is that it is *parathermal*, the diminishing elastic force of the springs with rise of temperature being compensated by a similar decrease of potential of the mercury column, which decrease depends upon the proportions given to the areas of the steel tube and its cup-like extensions.

The instrument is suspended a short distance above its centre of gravity in a universal joint, in order to cause it to retain its vertical position, notwithstanding the motion of the vessel; and vertical oscillations of the mercury are almost entirely prevented by a local contraction of the mercury column to a very small orifice. The reading of the instrument is effected by means of electrical contact, which is established between the end of a micrometer-screw and the centre of the elastic diaphragm. The pitch of the screw and the divisions upon the rim are so proportioned that each division represents the diminution of gravity due to one fathom of depth.

Variations in atmospheric pressure have no effect upon the reading of this instrument; but a correction has to be made for variations of atmospheric density as affecting the relative weight of the mercury column, which correction might be avoided, however, in excluding the atmosphere from both the upper and the lower surface of the mercury, and connecting the extremities of the column. The only necessary correction is that for latitude, which it is asserted in the paper must be less variable on the sea than on land, owing to the absence of masses elevated above the surface, and owing to the comparative greater distance of the irregular solid constituents of the earth and the very uniform density of sea-water.

The paper contains tables of the result of actual observations of the instrument in twice crossing the Atlantic on board the steamship 'Faraday,' while she was engaged upon laying submarine cables. The readings of the instrument were checked by actual soundings taken by means of Sir William Thomson's steel-wire sounding-apparatus; and the comparable results agree in all cases as closely as could have been expected, considering that the sounding-line gives the depth immediately below the vessel, whereas the bathometer gives the mean depth taken over a certain area, depending for extent upon the depth itself; it is also shown that upon an even slope the two instruments may be expected to agree in their indications.

It is thought that the bathometer may render useful service to the mariner in warning him of changes of depth long before reaching dangerous ground. An example is recorded where the position of the end of a submarine cable in deep water was found simply from a knowledge of the depth in which the end had been lost; and it is shown how the position of a vessel, when no astronomical observations can be taken, may be ascertained by the aid of a bathometer, provided the contour-lines of equal depths of oceanic basins were accurately laid down.

The instrument is applicable also for measuring elevations above sea-level; and it is shown that for height the total attraction of the earth varies in the ratio of

$$h : \tfrac{1}{2}\mathrm{R},$$

and that therefore approximately the fathom-readings at sea may be taken for yard-readings in measuring height; but that in this last application allowance will have to be made, in addition to corrections for latitude, for the local attraction of the elevated land itself, varying with its breadth, and rendering the indications of the instrument for height less reliable than for depth of sea.

ADDENDUM.—On an Attraction-meter. Received February 23, 1876.

At the reading of the foregoing paper, the author exhibited an instrument for measuring horizontal attractions, which, at the same time, illustrates the action of the bathometer. This instrument consists of a horizontal tube of wrought iron 400 millims. long, terminating at each end in a horizontal transverse tube of cast iron of 60 millims. diameter and 300 millims. long. The first-named horizontal tube is partially closed at its ends, and communicates with the transverse ubes below their horizontal mid section. The transverse tubes communicate also by means of a horizontal glass tube of 2 millims. diameter at a superior level to the former.

The whole apparatus being mounted upon three set screws is filled to the level of the half-diameter of the transverse tubes with mercury, which mercury fills also the whole of the longitudinal connecting-tube; the upper halves of the cast-iron transverse tubes and the glass connecting-tube are filled with alcohol tinted with cochineal, comprising, however, a small bubble of air, which can be made to occupy a central position in the glass tube by raising or lowering the set screws.

If a weighty object is approached to either extremity of the connecting-tube an attractive influence will be exercised upon the mercury, tending to a rise of level in the reservoir near at hand, at the expense of the more distant reservoir; and this disturbance of level between the two reservoirs must exercise a corresponding effect upon the index of air in the horizontal glass tube, moving it away from the source of attraction. The amount of this movement must be proportionate to the attractive force thus exercised, and is considerable, because the transverse cross section of each reservoir-tube is $60 \times 300 = 18{,}000$ square millims., whereas the section of the glass tube is only about 3 millims.; the motion produced by the effect of gravity is thus increased 3000-fold, and could easily be increased, say 30,000-fold, by simply increasing the horizontal area of the transverse or reservoir-tubes. Variations of temperature have no effect upon this instrument, because the liquids contained on either side of the index of air are precisely the same in amount; and the total expansion of the liquids is compensated for by an open stand-tube rising up from the centre of the connecting-tube, through which the apparatus can be easily filled. By means of this instrument the effect of 1 cwt. approached to one end or the other of the mercury connecting-tube causes a sensible motion of the air-index.

It is suggested that an instrument of this description may be employed usefully for measuring and recording the attractive influences of the sun and moon which give rise to the tides. The instrument, which is of simple construction and not liable to derangement from any cause, would have to be placed upon a solid foundation with its connecting-tube pointing east and west, records being taken either by noting the position of the index upon the graduated scale below, or by means of a self-recording arrangement through photography.

This mode of multiplying the effect produced by gravitation is shown as applicable also to the bathometer; and the author showed one of these instruments fitted with a spiral glass tube laid horizontally upon the upper surface of the bathometer upon a regularly divided scale, which horizontal tube is connected at one end with the uppermost chamber of the bathometer above the mercury, while the other end remains open to the atmosphere. The space above the mercury in the upper chamber is filled by preference with oil, which terminates in the horizontal spiral glass tube at a point which will vary with the total attractive influence of the earth, and thus furnish a means of reading the instrument. The electric contact arrangement described in the paper is thus rendered unnecessary, and the reading of the instrument much simplified.

II. "On Instruments for Recording the Direction and Velocity of Currents and the Temperature of the Water at different Depths in the Ocean." By J. Rymer Jones, of the Imperial Government Telegraphs, Japan. Communicated by Prof. Rymer Jones, F.R.S. Received January 1, 1876.

The object of these instruments is to register on board ship :—

1st. The direction of currents which flow at different depths in the ocean.

2ndly. The velocity of those currents.

3rdly. The temperature of the sea at all points between the surface and bottom, without requiring the instruments to be hauled up in order to register the results.

The advantages of such results, if capable of being obtained, must appear self-evident; and the following description will, I hope, prove the practicability of those methods which I propose to adopt in order to arrive at the above desiderata.

All three instruments are based on electrical principles.

Diag. 1. fig. 1 represents a full-sized section of the instrument employed for making serial observations of the direction of currents flowing at different depths in the sea; and in the lower part of the same figure is shown the method for taking the temperatures at the same points; but as the description of this instrument will form a separate paragraph, I shall dismiss it for the present with the remark that the same leading-wires are used in connexion with both instruments.

In considering the best method for registering the direction of deep-sea currents, two things seem absolutely necessary :—1st, some point capable of taking up a fixed direction and uninfluenced by the currents; and 2ndly, a movable point taking up the direction of, and regulated by, the current whose direction is required. With these data it appeared sufficiently easy to arrive at the direction of the currents, by measuring the angle between the fixed point and the movable point, which varies with the direction of the current. It is clear that the only available fixed point is that afforded by the unerring magnet, while the employment of a sufficiently large vane will cause the instrument to take up a position in the direction of the current, the rest being only matter of detail, which I now proceed to discuss.

In order to keep the magnet in a perfectly horizontal position and un-